Whale survey data indicate that humpback and blue whale numbers have increased significantly in the Santa Barbara Channel, including around the VTSS, over the last 20 years (Howorth 2004). This hopeful information may disqualify the possibility of cetacean avoidance or abandonment of Channel Islands habitat due to shipping noise. Nonetheless, as discussed above, large vessel traffic is projected for roughly 5-10% annual growth for many more years. Barring a significant change in large vessel traffic patterns through the Santa Barbara Channel, it remains to be seen if a threshold of tolerance for habitat ensonification exists for CINMS whales. In the meantime, the several documented incidents of long-term abandonment of even critical habitat due to anthropogenic noise should implore Sanctuary stakeholders to be alert for changes in both the ambient noise levels and local whale population numbers in the Sanctuary.

Apart from marine mammals, fish also show sensitivity to anthropogenic noise. While no in-depth studies have yet been completed on impacts to fish specifically from large vessel traffic noise, current research of hearing in fishes and the impacts of sound on fish ecology strongly suggest that loud anthropogenic sound and increases in ambient noise level can have significant impact on fish species. Data from such studies, summarized below, should also be considered in the context of shipping noise and CINMS.

Most species of fish, including the cartilaginous species like sharks, rays and skates, have inner ear physiology very similar to terrestrial vertebrates, and are able to detect sounds from well below 50 Hz (some as low as 10 or 15 Hz) to 1,000 Hz (some species show acuity to 10 kHz and beyond); all species of fish tested have been able to hear (Popper 2003). This implies fish sensitivity to most, if not all, of the spectrum of emissions from large vessel traffic, and thus the potentiality of consequences similar to those faced by marine mammals, that could similarly impinge on individual and population survival, including masking of biologically important sound, auditory tissue damage (threshold shifting), avoidance of otherwise suitable habitat, and chronic stress.

Many fish species depend on sound for navigation, reproduction, foraging, and as a cue for avoidance of peril, whether emitted from their physical environment, from conspecifics (other individuals of the same species) or from predator or prey species (Popper 2003). An increase in ambient noise level, whether from constant large vessel traffic or another noise source, could alter fish behavior (NRC 2003); alteration of any of these crucial behaviors could obviously impact survival. As one example, Popper (2003) mentions how shark species are attracted to the sound of prey struggling in the water, and the increased difficulty in finding food in noisy environments in which such sound is masked. NRC summarizes important research on the impact of masking on recruitment in reef fishes whose life cycles have an offshore larval stage:

> *...at least some larval fish are likely to use the reef sounds to find the reefs and that the fish will go to regions of higher-level sounds (Tolimieri et al., 2003). Thus, if there are intense offshore sounds, larval fish may be confused and not be*

able to find the reef. Alternatively, such sound may mask reef sounds, again preventing larval fish from finding the reef. [NRC 2003]

That large vessel traffic noise has the potential to impact Sanctuary fishes reveals the need to better understand the magnitude and character of the threats to CINMS fishes specifically. Useful research may include necropsy of fish ears from animals with a high exposure rate to shipping noise, e.g. from near the north shore of Anacapa. Concurrently, continuous monitoring of the Sanctuary's acoustic environment in several locations would provide basic data on approximate exposure rates for all marine species, as well as establish a useful baseline to compare future anthropogenic output.

NRDC (1999) reports that, *"managers at Monterey Bay and other sanctuaries have thought to form voluntary associations with shippers, mainly to reduce the risk of oil spills sludging up protected waters, but also to guard against habitat degradation and acoustic harassment[9]."* Currently this partnership routes volunteering oil tankers outside the Santa Barbara Channel to approximately 50 miles off the coast. From the perspective of managing the CINMS acoustic environment for wildlife conservation, encouraging the routing of the largest and loudest vessels a similar distance offshore may ameliorate the risk to Sanctuary ecology posed by the large vessel traffic output.

ACTIVE SONAR

Active sonar, in which sound is broadcast and its echoes recorded in order to "characterize physical properties and locate marine objects," is divided into low-frequency (<1 kHz), mid-frequency (between 1 and 10 kHz), and high-frequency (>10 kHz) (NRC 2003). Currently, active sonar is not assessed to directly impact CINMS ecology. However, the extreme intensity of sound levels broadcast by low- and mid-range active sonar and the dramatic impacts associated with its application, as well as the national and global proliferation (NRDC 1999) of all ranges of active sonar technology, warrant its assessment as an ecological threat worthy of this discussion and for consideration from the standpoint of CINMS biological resource management.

High-frequency active sonar has an array of applications, including civilian use for fish-finding; vessel side-scanning or high resolution sea-floor imaging, and military use for side-scanning and mine hunting (NRC 2003). Development and testing is also currently underway for hull-mounted "whale-detecting" high frequency active sonar, aimed at reducing shipstrike.

Due to the physical characteristics of high frequency sound used by these systems (approximately 10 to 500 kHz), emissions are quickly absorbed in seawater and thus localized in effect. Detailed understanding of the impacts of high-frequency sonar on

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9/ Personal communication between NRDC authors and Ed Cassano, former Manager, Channel Islands National Marine Sanctuary (July 23, 1997).

either specific species or general ecosystems has yet to be articulated[10]. However, delfinids (species of the dolphin family) such as bottlenose (*Tursiops truncates*) and common dolphins (*Delphinus delphis* and *Delphinus capensis*) which rely heavily on echolocation have acuity at high frequencies (into ultrasonic range) for their own active sonar, and certain fishes of the family Alosinae that range through the Santa Barbara Channel, including American shad (*Alosa sapidissima*) (an introduced species) and Pacific herring (*Clupea pallasii*) have aural sensitivity of 10 kHz and beyond (perhaps for detection of predatory bottlenose dolphins, or communication with conspecifics) (Mann et al. 2001, Wilson et al. 2003). Use of high frequency sonar may thus impact behavior and survival of these species through masking or causing avoidance of habitat if used extensively or in ecologically sensitive areas within the Sanctuary.

In contrast, mid- and low-frequency active sonars are limited to naval (military) application. NRC (2003) summarizes the systems and their respective application:

> *Military sonars are typically operated at higher power levels than civilian sonars and are used for target detection, localization, and classification. Military low-frequency sonars are used for surveillance and are designed to gather information over large areas. If conditions permit, these sonars can collect information over entire ocean basins. The mid-frequency military systems are tactical sonars and are designed to look over tens of kilometers for the localization and tracking of targets.*
>
> *The class of surveillance sonars presently in the fleet is designed to locate targets, primarily submarines and to some extent surface ships, at tens to hundreds of kilometers away to provide early alerts of potential threats to navy vessels. The U.S. Navy's Surveillance Towed Array Sensor System Low Frequency Active (SURTASS-LFA) system utilizes a vertical line array of up to 18 source projectors operating in the frequency range of 100-500 Hz. The source level of each projector is approximately 215 dB.*
>
> *In addition, the U.S. Navy reports that the hull-mounted AN/SQS-53C tactical* [mid-frequency] *sonars can generate pulses in the 1-5 kHz band and have been operated at source levels of 235 dB, and that the AN/SQS-56 sonars generate pulses in the 5-10 kHz band and have operated at 223 dB source levels.* [Evans and England 2001]

Impulsive sound of these extreme source-levels has very high potential for negative impact to marine wildlife on several levels, from individual physiology to general ecology. Pertinent implications for low and mid-range frequency sonar vary based on their respective frequencies, and thus will be individually addressed in turn.

10/ An effort to initiate commercial testing of high-frequency systems off the Central Coast for vessel-based detection and avoidance of whales has caused some controversy (See: San Francisco Chronicle, 1/17/04, "Judge allows tests of sonar for sake of finding whales").

The high intensity, impulsive sound in the 1kHz-10kHz range that characterizes mid-frequency sonar has been implicated in cetacean fatality stemming from acoustic trauma (Evans and England 2001) and decompression sickness (resultant from startle/flight response triggering ascension at excessive velocity) (Jepson et al. 2003), mass stranding (WDCS 2003; summarizing four incidents), severe damage to hearing physiology (Evans and England 2001), alteration of vocalizing behavior (Watkins et al. 1985, Rendell and Gordon 1999) and abandonment of habitat (Parsons et al. 2000).

Findings of the Evans and England (2001) report are worth highlighting. The joint report of NOAA and the US Navy stated that mid-frequency tactical sonar used by several ships within 24 hours of a mass stranding of Cuvier's beaked whales (*Ziphius cavirostris)* and a Blainville's beaked whale (*Mesoplodon densirostris*), on the northern Bahamas coastline, was the most plausible source of the acoustic trauma that caused the beaked whales to strand. The writers base this conclusion on recordings from NOAA operated hydrophone arrays in the Atlantic and Caribbean which reveal the tactical sonar as the only sound present during the time period capable of causing the physiological trauma suffered in the cranial cavities, aural structures and tissues of the odontocetes, and on the results of extensive computed tomography (CT) scanning and autopsy work performed for the investigation.

The Jepson et al. (2003) report is similarly worth elaborating upon, as the researchers also gathered detailed pathological data implicating tactical sonar in beaked whale mass stranding and death. In their case, "fourteen beaked whales were stranded in the Canary Islands close to the site of an international naval exercise in September 2002. Strandings began about 4 hours after the onset of mid-frequency sonar activity." Jepson et al. performed necropsy on eight Cuvier's beaked whales, a Blainville's beaked whale, and a Gervais' beaked whale (*Mesoplodon europaeus*), "six of which were very fresh." The necropsies of these individuals revealed "[i]ntravascular bubbles... present in several organs," which they propose, as mentioned, was representative of decompression sickness caused by excessively rapid ascension from depth. Unfortunately the researchers did not have hydrophonic data to reference with the incident, however they note that their observations are "unprecedented in marine mammal pathology," implying extraordinary causal circumstances.

Further incidents in which the use of mid-frequency active sonar has been implicated in cetacean harm or death, through coincidence with mass stranding, have occurred throughout the world. These include: Madeira, Spain (2000), Kyparissiakos Gulf, Greece (1996), Puerto Rico, and Washington state (2003) (NOAA 2002, WDCS 2003), and, in 2004, in Hawaii[11] (a "near-stranding") and the Canary Islands[12].

11/ "Navy's use of sonar suspected in near-stranding of whales: Hawaii incident intensifies debate on ocean noise." Marc Kaufman, September 1, 2004. Published by the *Boston Globe*.

12/ "Dead whales found after military exercise: Off Spanish coast, latest case follows new report blaming sonar tests." Reuters: Fuerteventura Coast, Spain. July 23, 2004. Published at http://msnbc.msn.com/id/5488866/.

Clearly, naval tactical mid-frequency sonar represents a danger to marine wildlife, particularly odontocetes such as beaked whales with particular aural acuity in frequencies typically used in these sonar systems. Pertinent to CINMS wildlife, specifically its odontocete communities[13], NOAA and the US Navy (Evans and England 2001) have outlined mitigation measures to reduce marine mammal take from mid-frequency sonar deployment:

> *1. Forego multi-ship, peacetime active sonar transmissions from mid-range tactical sonar in the Northeast and Northwest Providence Channels* [of the Bahamas] *unless required for National Security reasons.*
>
> *2. The Navy will carefully assess and closely scrutinize future training and training areas with an eye toward avoiding those situations where the combination of factors presented in this report (oceanography, bathymetry, sonar usage, etc.) would be likely to occur.*
>
> *3. If the factors cited in this report are present in another location, and relocation is not feasible, and the Navy must proceed but has not received a Letter of Authorization (LOA) or an Incidental Harassment Authorization (IHA), then:*
> *• Immediately before the operation use whatever facilities or assets are on hand to visually and acoustically survey for marine mammals*
> *• Establish a zone of influence appropriate to the existing oceanographic conditions and source level settings*
> *• Employ properly trained lookouts*
> *• Implement shutdown procedures if marine mammals are detected within the zones of influence established for those species*
> *• Immediately after the operation ends (where feasible, usually in near shore waters) survey for injured, disabled or dead marine mammals using whatever survey facilities and assets are on hand, and notify NMFS if any such animals are found so that an appropriate stranding response can be implemented.*
>
> *4. NMFS will continue to conduct broad area surveys of marine mammal locations, migratory pathways and habitats that can be used by Navy planners in selecting exercise sites.* [Evans and England 2001]

Measures (2) and (4) imply that the Navy and NOAA Fisheries must consider the biological richness of prospective mid-frequency sonar activities sites before deployment. Such consideration may suggest that CINMS will be outside the zone of influence of any future West Coast naval exercises involving tactical sonar. While this suggestion is reasonable and reassuring, the stringency of the Navy's application of the mitigation

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13/ The acoustically sensitive Cuvier's and Baird's beaked whales are known to occur in Southern California, as well as several other beaked whale species including Blainville's, Hubb's, Ginko-toothed, Perrin's, and Stejneger's beaked whales (Leatherwood et al.1987).

measures is unknown, and thus the future impacts of tactical sonar on CINMS remains uncertain.

Low frequency active sonar (LFAS) is currently a more nascent and extraordinary technology than active mid-frequency sonar. Designed as a strategic oceanic surveillance system to monitor ultra-quiet "enemy" submarines that elude detection by passive hydrophones, the US Navy considers the technology a necessity for national security and protection against the "224 submarines operated by non-allied nations… prowling the world's oceans" (US Navy 2004). LFAS takes advantage of the low attenuation rate of low-frequency sound waves in seawater, as well as the thermoclines in the oceanic water column that confine sound waves to layered channels of water of distinct temperature, to transmit sound and receive its echoes over thousands of kilometers (NRC 2003). NRDC summarizes the Navy's Surveillance Towed Array Sensor System of low frequency active sonar (i.e. SURTASS LFA):

> *Eighteen separate loudspeakers, each one slightly smaller than a bathtub, are lowered from the vessel's hull 300 to 500 feet downward. The speakers are synchronized through electrical lines running the length of a central cable, and when the proper code is entered on the ship's computer and the LFA protocol is launched, they sound in tandem, creating at several hundred meters a focused beam of intense, deep noise: a series of pure tones and frequency sweeps pitched somewhere between 100 Hz and 500 Hz, and reportedly reaching over 230 decibels. The point at which the individual sound waves converge varies with their frequency. Given the length of the 18-speaker array (approximately 57 meters) and the average speed of sound in water (1500 meters/second), transmissions of 100 Hz and 500 Hz meet at roughly 110 meters and 540 meters, respectively. Within this range, zones of great intensity alternate with pockets of relative quiet.*

In court proceedings, the Navy has acknowledged that SURTASS-LFA sound transmits at such intensity to have a received level of around 140dB more than 650 km from the sound towed array sound source (*NRDC, et al. v. Evans, et al.*, 2003). Obviously, huge geographic areas would be ensonified and thus potentially impacted by operation of even a single array. SURTASS-LFA has been in testing since 1994 at the latest (WDCS 2003) (including, in rather direct relation to our discussion, at least two test exercises in the 1990's "south of the Channel Islands" (NRDC 1999)).

Study of potential biological impacts from LFAS to marine wildlife has thus far focused on cetaceans, specifically the great whales which, as mentioned earlier, have significant or primary aural sensitivity to low frequency sound. Dr. Peter Tyack, writing in NRDC (1999), summarizes three US Navy-sponsored studies in which he took part that attempted to assess great whale reaction to LFAS sound:

> *Three different species and settings were selected, the first involving blue and fin whales feeding in the Southern California bight (Sept.-Oct. 1997); the second,*

gray whales migrating past the central California coast (Jan. 1998); and the third, humpback whales breeding off the Hawaiian Islands (Feb.-Mar. 1998). For each experiment, researchers broadcast a series of low-frequency pulses and waves that simulated the LFA signal (albeit at lower intensities), and monitored the reactions of the local whales. Our primary focus was avoidance-- but attention was also paid to such issues as whale vocalization and mother-calf behavior. Our preliminary analyses did reveal reactions of whales to LFA playbacks. During the first experiment, the number of fin and blue whales heard vocalizing decreased during playback. During the second experiment, gray whales deviated from their migration paths[14]*: the louder the sound, the greater the avoidance reaction. During the third experiment, about a third of the singing* [humpback] *whales stopped singing in response to the LFA playback* [see also Miller et al. (2000), describing humpbacks lengthening songs in response to LFAS sound.]. *We determined the acoustic exposure for each whale that was a subject in these playback experiments; this allows us to develop a model of what exposure conditions evoke these different responses. There remains the critical issue of estimating the biological significance of these responses to low-frequency sound.* [NRDC 1999]

While cessation or increase of duration of vocalization could be construed as a minimal impact, NRC cautions against such assumptions, stating:

Clearly there are opportunity costs associated with even the transient behavioral changes in response to noise. The movements require energy that might otherwise have been spent in acquiring food or mates or enhancing reproduction. Repetitive transient behavioral changes have the potential of causing cumulative stress. Even transient behavioral changes have the potential to separate mother-offspring pairs and lead to death of the young, although it has been difficult to confirm the death of the young. [NRC 2003]

Testing and deployment of the SURTASS-LFAS was suspended in autumn of 2003 as a result of a lawsuit by NRDC challenging the US Navy's compliance with the Marine Mammal Protection Act (MMPA). According to NRDC, the presiding judge "found that a permit issued to the Navy by the National Marine Fisheries Service to deploy LFA sonar violates the MMPA, the Endangered Species Act (ESA) and the National Environmental Policy Act (NEPA) because it did not adequately assess or take steps to mitigate the risks posed by the system to marine mammals and fish[15]."

14/ "Migrating gray whales diverted around a stationary sound source projecting playbacks of LFA sonar when the source was located in the migratory path but seemed to ignore the sound source when it was located seaward of the migratory path. When the source was in the path, received levels of 140 dB re 1 μPa were sufficient to cause some path deflection." (NRC 2003, citing Tyack and Clark 1998, unpublished)). As mentioned, LFAS sound can have a received level of 140 dB more than 400 miles from the source.

15/ http://www.nrdc.org/media/pressreleases/030826.asp

In the Autumn 2003 ruling, the Court issued an injunction against proceeding with deployment of SURTASS-LFAS, until a "carefully tailored" agreement is established between NRDC and co-plaintiffs, NOAA and the Navy that allows "the Navy to meet its needs for peacetime training and testing, *while also* providing reasonable safeguards for marine mammals and other sea animals." Judge Laporte elaborates:

> *The Court's injunction will permit the Navy to train and test LFAS in a wide range of oceanic conditions as needed, while restricting it from operating in certain sensitive areas when marine mammals are particularly abundant there. In particular, the injunction will extend the coastal buffer zone beyond the current twelve miles to include more of the continental shelf in the great majority of coastlines where the record shows that the Navy need not operate closer to shore. The injunction will also require the Navy to avoid certain areas of the deep ocean during seasons when data on marine mammals and other endangered species such as sea turtles shows that they are migrating, breeding, feeding or otherwise clustering there. The evidence in this case shows that this kind of data is available to enable the Navy to refine its operations in order to afford reasonable protections to marine life, while still meeting its testing and training needs. Indeed, the Court appreciates that, in response to the preliminary injunction issued earlier, NMFS and the Navy have decided to engage in further analysis of this kind of data for potential use in planning routes that minimize sea creatures' exposure to the sonar. Further, where the Navy needs to operate close to shore in areas where sea life tends to be abundant and where conditions may make strandings of whales more likely, whenever feasible the Navy shall use additional measures to check for the presence of marine mammals before activating the sonar. In sum, the Navy and NMFS can fully comply with environmental laws and also meet the need to test and train with this new type of sonar.* [*NRDC* v. *Evans*, 2003]

Clearly this injunction pertains to areas of biological richness and significance such as CINMS (and other national marine sanctuaries), and thus implies a level of protection for the Sanctuary.

Subsequent to the Court's decision, the US Navy and NRDC reached agreement to restrict SURTASS-LFAS operation to certain areas of the Western Pacific (across the Pacific Ocean basin from CINMS), until the Navy corrects the legal deficiencies in the program identified by the court (Horowitz 2004).

While this litigation will likely lead to more ecologically-sensitive LFAS-SURTASS deployment by the US Navy in the future, proliferation of LFAS systems among other national and coalition navies not subject to environmental protection requirements is predicted (NRDC 2003), based on historical patterns of military technology dispersion (the globally imperiling one-upsmanship of an arms race). In support of this prediction, the *Taipei Press* reported on February 15, 2004 that the US has agreed to sell two land-mounted LFAS arrays to the Taiwanese navy, for deployment by 2006; subsequent deployment by the Chinese navy of a countervailing LFAS system seems like a probable result. Meanwhile, the British Royal Navy continues to test their LFAS system, towards imminent deployment under NATO (NRDC 1999).

While LFAS currently remains a nascent technology of limited distribution, Sanctuary ecology may yet be impacted by its deployment. The acoustic background of CINMS would likely undergo discernable increase from sonar use hundreds of kilometers away, while arguably inevitable proliferation of LFAS could increase the chance of both direct impacts on the Sanctuary, or impacts on transient or migratory species that temporarily inhabit CINMS but suffer exposure to LFAS sound elsewhere.

HIGH ENERGY SEISMIC SURVEYING

Seismic surveying. Note towed airgun array. (Photo: IEA Greenhouse Gas R&D Programme, UK)

Seismic-surveying involves synchronized firing of a towed airgun array. Airguns fire quantities of high-pressure (approximately 2000psi) air vertically into the water, directing 10Hz-300Hz (low-frequency) impulsive sounds toward the sea floor so that sound waves penetrate the geology and reflect back to sensors (Lissner and Greene 1998). Analysis of received echoes provides sub-sea geologic imagery, and thus yields information such as the presence of extractable hydrocarbons (oil and natural gas) and tectonic characteristics (WDCS 2003, NRC 2003). Peak source levels for seismic surveying typically exceed 200 dB, and exceed 250 dB in some surveys with a high total array volume (combined volume of all guns in the array, a number that captures both the size of the guns and number of guns involved) (Engås et al. 1996).

The sub-sea geology of the Santa Barbara Channel area has been subject to seismic surveying in the past for both scientific and commercial purposes (Lissner and Greene 1998; Calambokidis et al. 2002; Pierson 2004). Future surveying for both purposes is possible: the imperative for greater understanding of the tectonically dynamic South Coast area may motivate researchers to conduct further surveying, while a significant increase in global oil and gas prices could stimulate future offshore prospecting for oil or gas in deep water areas currently considered uneconomical.

Acoustically, seismic-surveying sound is significantly directional; sound of 230-255 dB between 10Hz and 100Hz is typical in the downward direction (Richardson et al. 1995). This is of particular concern for deep diving marine mammals such as elephant seals, sperm whales, beaked whales, and any fishes, reptiles or invertebrates that may be present in the water column between the targeted seafloor and the operating airgun array. Documentation of physiological impacts to wildlife from close range exposure to seismic surveying sound is limited, however the existing reported outcomes associated with such exposure, described below, suggest the potential for significant injury in at least cetaceans and fishes (no studies or documentation of impacts on marine invertebrates, reptiles or birds are known to exist).

McCauley et al. (2003), in perhaps the most comprehensive study to date on direct physiological impacts to wildlife from airgun noise, report on damage to hearing structures and tissue in several fish species subject (through cage confinement) to airgun blasts at a variety of distances. Necropsies of the subsequently sacrificed pink snapper revealed the following:

> *Fish exposed to an operating air-gun sustained extensive damage to their sensory epithelia that was apparent as ablated* [destroyed or missing] *hair cells. The damage was regionally severe with no evidence of repair or replacement of damaged sensory cells up to 58 days after air-gun exposure.* [McCauley et al. 2003]

As discussed in "Large Vessel Traffic", many fish species depend on hearing function for an array of behavior essential for survival. Hearing loss from excessive exposure to airgun sound could thus impinge on the survival of individual fish or fish populations.

No studies have yet been conducted to determine direct (physiological) impacts of airgun noise on marine mammals; research has been limited to recording of visually observed behavioral responses within a small radius of operating seismic surveying projects (WDCS 2003) (see Calambokidis et al. 2002, for example).

However, the body of incidental evidence continues to grow. In 2002, episodes of increased humpback whale strandings in coastal Brazil coincided with commercial seismic surveying in the area (IWC 2004(b)). Also in 2002, two Cuvier's beaked whales (*Ziphius cavirostris*) that appeared to be in good physical condition and disease-free, stranded and died on Isla San Jose in the Gulf of California, in proximity to geology research involving seismic surveying. The project, conducted by the National Science Foundation's (NSF) R/V *Maurice Ewing*, involved operation of a 2000 psi, 20 unit, 8300 cubic-inch, tuned airgun array with source levels of at least 263 dB at low frequencies (LDEO 2004). NOAA Fisheries scientists coincidentally in the area contemporaneous with the surveying testified that they believed the airgun sound caused the cetaceans to strand and die (in a manner similar to the stranding deaths of acoustically traumatized beaked whales in the Bahamas). Unfortunately both carcasses were too decomposed to investigate for the implicated acoustic trauma (WDCS 2003). Nonetheless, a temporary restraining order was subsequently issued in US District Court halting the experiment after Judge J. Larson found that operation of the airgun array was likely in violation of the National Environmental Policy Act and the Marine Mammal Protection Act, and likely to cause irreparable harm to beaked whales in the Gulf of California where surveying was occurring (Teel 2004, *Center for Biological Diversity (CBD) v. NSF,* 2002). Judge Larson also pointed out that, as "easily-spooked" (resulting in diving response), and deep-diving foragers, beaked whales are both highly susceptible to injury from seismic surveying, and not likely to be spotted to trigger mitigation or shut-down protocols (*CBD v. NSF,* 2002).

A later settlement between CBD and the NSF formalized a more precautionary protocol for the *Maurice Ewing* to better prevent marine mammal harassment and injury while operating the airgun array (Teel 2004).

Strandings in Brazil and in the Gulf of California, and the US District Court decision indicate that, while comprehensive research has yet to be completed on the physiological impacts on marine mammals from seismic surveying sound, such exposure can likely have significant, even lethal consequences. Furthermore, until more comprehensive data on the impacts of airgun noise on marine mammals becomes available for permitting, any future seismic surveying in the CINMS area should be managed with precaution to preclude such impacts on Sanctuary species.

Significant sound propagation perpendicular to the aimed direction of firing airguns also occurs, implicating seismic surveying in substantial contribution to ambient sound levels in large areas around the shooting. WDCS (2003) reports that sound from seismic surveys conducted off Nova Scotia were "prominent in the acoustic background off the Bahamas and along the Mid-Atlantic Ridge, several thousands of kilometers away." A study conducted in 1998 involving shooting with a small (8 unit) airgun array near Platform Harmony off Gaviota (northwest of Santa Barbara) determined that, with a measured peak source level of 232 dB, the airgun sound superseded ambient noise levels in the frequency range 20 Hz to 2000 Hz by up to 20 dB, more than 6 km away. The researchers also reported that between 130 and 180 meters from the airguns, received sound levels were still at 180 dB, the sound level threshold identified by NOAA Fisheries and the US Navy as detrimental to marine mammals (Lissner and Greene 1998). Seismic surveys designed to generate three-dimensional images of a geological region can involve thousands of low-frequency airgun shots of 220 dB or greater. The last full-scale survey in the Santa Barbara Channel, conducted in 1995, lasted over a month, and covered an area of approximately 300 square kilometers (Pierson 2004).

Studies of behavioral impacts on marine wildlife from airgun noise reveal that entire populations of a variety of species respond to surveying (or surveying sound). Dahlheim (1993) tracked route deviation in migrating gray whales exposed to a stationary sound source playing recorded airgun sound, and reported that avoidance of the noise resulted in course deviation from the noise roughly proportional to the sound level of playback. Corresponding data in the Western Pacific exist as well: displacement from a primary feeding area off Sakhalin Island by the endangered western North Pacific gray whale population because of seismic activity is reported (IWC 2004(b)).

Engås et al. (1996) studied the effect of seismic surveying (with an airgun array with peak levels at approximately 255 dB in the 20-150Hz range) on fisheries off the coast of Norway. Their abstract summarizes the information pertinent to this discussion:

> *Seismic shooting severely affected fish distribution, local abundance, and catch rates in the entire investigation area of 40x40 nautical miles. Trawl catches of cod and haddock and longline catches of haddock declined on average by about 50% (by mass) after shooting started, which agreed with the acoustic abundance estimates; longline catches of cod were reduced by 21%. Reductions in catch rates were observed 18 nautical miles from the seismic shooting area (3x10 nautical miles), but the most pronounced reduction occurred within the shooting area, where trawl catches of both species and longline catches of haddock were reduced by about 70% and the longline catches of cod by 45%; a relatively greater reduction was found (in catches and acoustic estimates) for large (>60 cm) than for small fish. Abundance and catch rates did not return to preshooting levels during the 5-day period after seismic shooting ended.* [Engås et al. 1996]

Løkkeborg and Soldal (1993) also investigated seismic surveying impacts on fisheries through analysis of catch data obtained from commercial vessels operating on fishing grounds where seismic surveys were being conducted. They found a 56% reduction in longline catches of cod and a reduction of 81% in the by-catch of cod in shrimp trawling.

Engås et al. (1996) also report that seismic surveying at the levels they observed is sensed and reacted to by fish as far as 30-100km from the sound source, reinforcing the immensity of the range of impact of past and future surveying in the Santa Barbara Channel.

Collectively, this information suggests that any future surveying in the Santa Barbara Channel will contribute significantly to the Sanctuary's acoustic environment, and may impact cetacean individuals and communities, fish and fisheries, and other interdependent members of Channel marine ecology. Reinforcing this conclusion, the Scientific Committee of the International Whaling Commission recently stated that it "views with great concern the impacts on large whales in critical habitats from exposure to seismic sound impulses," and thus recommends that "all seismic surveys in areas that could have significant adverse demographic consequences for large whales should be planned so as to be out of phase with the presence of whales" (IWC 2004(a)). The importance of CINMS to large whales and other wildlife is well known-- the importance of implementing the IWC recommendation locally should be equally clear. Sanctuary resource managers must be aware of any future proposed seismic surveying that may impact CINMS wildlife and ecology, while mineral and biological resource managers must coordinate as recommended to minimize cetacean harassment and harm from survey noise.

SMALL SHIPS, BOATS AND PERSONAL WATERCRAFT

Small ships are characterized as typically diesel-powered, twin propeller craft roughly 55-85m in length, producing broadband (20-1000Hz) noise between 130-141 dB while operating. Nozzles are often fitted around the propellers to direct thrust and improve maneuverability, which also can significantly reduce sound emissions in some directions. Scientific research vessels such as the 70m *Maurice Ewing*[16] (discussed in the Seismic Surveying section above), commercial, and military support or supply vessels exemplify this category (Richardson et al. 1995). Boats 55m or less, which include most ferries and whale watching vessels in South Coast Harbors (such as the dive boat *Vision* and the charter/whale watcher *Condor Express*, both at approximately 26m in length[17]), and personal water craft such as jet skies, are typically powered by outboard motors or jet-thrusters (Richardson et al. 1995). While these vessels all produce constant, tonal underwater sound through mechanical operation, hydrodynamic flow and cavitation as described for large vessels, peak amplitudes for vessel emissions tend to occur at increasingly higher frequencies inversely proportional to the length of the given vessel (i.e. the smaller the vessel, the higher the peak frequency) (NRC 2003, Richardson et al. 1995). Sound of higher frequency attenuates, or is absorbed much faster in seawater compared to low-frequency sound (Roussel 2002), implying a less general, more localized acoustic effect from small vessels operating in and around the Sanctuary. Noise from small vessel traffic also tends to be concentrated in shallower coastal areas (NRC 2003), and is not concentrated in lanes, implying much more scattered and isolated underwater ensonification compared to large vessel traffic.

Channel Islands, Santa Barbara, and Ventura harbors provide slips and moorings for over 5000 recreational, commercial, and research vessels, while "numerous recreational, commercial, research and military vessels traverse the region while in transit between other ports" (CINMS 2003(a)). In Santa Barbara Harbor, 58% of vessels harbored in its slips and moorings are sail-powered[18]; assuming a roughly similar proportion for Ventura and Oxnard Harbors suggests that between 2,000 and 3,000 engine-powered small vessels operate off the South Coast. Unfortunately, it is unknown how many of these vessels enter the Sanctuary, or at what rate.

In sum, these characteristics establish small vessel traffic noise as a potential issue to smaller odontocetes and pinnipeds primarily, species that generally tend to be aurally attuned to higher frequencies[19] than the great whales, and tend to inhabit the shallower coastal regions where small vessels are prevalent (WDCS 2003, NRC 2003). However, unlike other baleen whales in the CINMS area, gray whales also tend to inhabit

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16/ See specifications at www.ldeo.columbia.edu/res/fac/oma/ewing/index.html

17/ Vessel specifications found at www.truthaquatics.com and www.condorcruises.com, respectively.

18/ Personal communication, Santa Barbara Harbor Master's office, April 29, 2004.

19/ Odontocetes commonly have good functional hearing between 200 and 100,000 Hz, although some species may have functional ultrasonic hearing to nearly 200 kHz. The majority of odontocetes have best hearing in the ultrasonic ranges, and moderate sensitivity to sounds from 1 to 20 kHz (NRC 2003).

shallower, coastal waters frequented by small vessels, and are thus also highly subject to potential impacts from small vessels noise.

NRC (2003) effectively captures the range of observed cetacean response to small vessel traffic noise in their discussion of beluga whales *(Delphinapterus leucas)*:

> *At distances of up to 50 km from... ships operating in deep channels, beluga whales respond with a suite of behavioral reactions. The reactions include rapid swimming away from the ship for distances up to 80 km; changes in surfacing, breathing, and diving patterns; changes in group-composition; and changes in vocalizations. The initial response occurs when the higher frequency components of the ship sounds, those to which the beluga whale are most sensitive, are just audible to the whales.*
>
> *Beluga whales in the St. Lawrence River appear more tolerant of larger vessels moving in consistent directions than they are of small boats, fast moving boats, or two boats approaching from different directions. Older animals were more likely to react than younger ones, and beluga whales feeding or traveling were less likely to react than animals engaged in other activities, but when the feeding or traveling whales did react, they reacted more strongly. In contrast to the lower rate of observed reactions of these beluga whales to larger vessels, a study of the response of beluga whale vocalizations to ferries and small boats in the St. Lawrence River showed more persistent reactions to the ferries. The whales reduced calling rate from 3.4 to 10.5 calls per whale per minute to 0.0 or under 1.0 calls per whale per minute while vessels were approaching. Repetition of specific calls increased when vessels were within 1 km, and the mean frequency of vocalizations shifted from 3.6 kHz prior to noise exposure to frequencies of 5.2-8.8 kHz when vessels were close to the whales.*
>
> *In Alaska, beluga whale response to small boats varies depending on the location. Beluga whales feeding on salmon in a river stop feeding and move downstream in response to the noise from outboard motorboats, whereas they are less responsive to the noise from fishing boats to which they may have habituated. On the other hand, in Bristol Bay beluga whales continue to feed when surrounded by fishing vessels and resist dispersal even when purposely harassed by motorboats.*
>
> *Thus, depending on habitat, demography, prior experience, activity, resource availability, sound transmission characteristics, behavioral state, and ever-present individual variability, the response of beluga whales can range from the most sensitive reported for any species to ignoring of intentional harassment. Beluga whales also show the full range of types of behavioral response, including altered headings; fast swimming; changes in dive, surfacing, and respiration patterns; and changes in vocalizations.* [NRC 2003]

This lengthy excerpt reveals the complexity of small vessel traffic noise as an issue to consider in the context of Sanctuary Management. The sporadic exposure of small vessel traffic noise that Sanctuary wildlife are subject to could potentially induce stress in individuals or groups of individuals of a given odontocete species, while other species or even conspecifics may be behaviorally impervious to the same sound due to habituation.

It's also critical to note that, in contrast to most of the baleen whales in the CINMS area, gray whales also tend to inhabit the shallower, coastal waters frequented by odontocetes, pinnipeds, and small vessel traffic, and thus also may be subject to impacts from small vessel traffic noise.

Useful to consider in this discussion are points raised in a study conducted by Erbe (2002) pertaining to orcas in the waters between British Columbia and the Olympic Peninsula. Resident pods of killer whales there face extreme levels of small vessel noise during the whale watch season, between mid-May and August. During this season in the years 1995-1999, groups of orcas were followed in the daytime by an average mean (the five-year average of each season's mean) of 21 private motorboats and commercial whale watch vessels at any given time; in the five seasons of Erbe's observation, a maximum of 60-70 pod-following motorboats were documented following at the same place at the same time.

Reviewing published literature on the behavioral impacts of whale watching on killer whales, Erbe shows that *orca* demonstrate a complex suite of effects similar to that of beluga whales, including avoidance of boats, attraction, shortened surfacing, longer dives, and interruption and termination of feeding and traveling behavior (2002). In general, however she states that "whales swam away from boats at speeds greater than those of undisturbed whales, and swimming speed increased with the number of boats present[20]" (Erbe 2002). Unpublished reports from other orca researchers in the Pacific Northwest indicate physiological effects typical of stress inducement from pursuit by even one whale watching boat, including increased respiration and heart rates (Anderson 2001).

The biological significance of observed behavioral responses to small vessel traffic is still unknown; questions remain as to whether whales disturbed from feeding by small vessels move to forage elsewhere, or sustain a reduced energy intake, and whether there are impacts to mating or rearing behavior (Erbe 2002). Nevertheless NRC (2003) reports on chronic stress as causal of fundamental impacts to cetacean survival, through the modulation of immune response. Roussel (2002) similarly states that such stress from chronic noise exposure can reduce immune function and increase marine mammal susceptibility to environmental toxins.

Erbe (2002) suggests that exposure to the extreme level of motorboat presence and noise (as well as inhabiting waters near a "busy, noisy commercial shipping lane") may be responsible for the lack of recovery from historical human killing and capture by the studied orca community, as well as the population's decline by almost 20% between 1995

20/ Erbe (2002) also notes importantly that research (Schevill 1968) has shown boat noise, not the mere presence of the boat, evokes marine mammal response.

and 1999. In what may be further illumination of the connection between vessel traffic noise and the resident orca population decline, Foote et al. (2004) report a general increase in the duration of orca vocalizations in tandem with the increase in attendant small vessels. They conclude that, in the approximately five-fold increase in vessels attending the southern resident orca population between 1990-2000, a threshold level of disturbance may have been crossed, initiating "a response… to counteract anthropogenic noise" (Foote et al. 2004). This data may provide an empirical basis for hypothetical connections between reductions in critical sensory and communications capabilities, and increased stress and reduced survival in the orcas.

To assist in development of an appropriate conservation-oriented management approach to this situation, Erbe applied a software-based "sound propagation and impact assessment model" to generate quantitative estimates. Her modeling results showed that,

> *When boat source levels ranged from 145 to 169 dB (increasing with speed)… the noise of the fast boats was modeled to be audible to killer whales over 16km, to mask killer whale calls over 14km, to elicit behavioral response over 200m, and to cause a temporary threshold shift in hearing of 5 dB after 30-50 minutes within 450 meters. Superposed noise levels of a number of [multiple] boats circulating around or following the whales were close to the critical level assumed to cause a permanent hearing loss over prolonged exposure.* [Erbe 2002].

CINMS wildlife do not currently face a concentrated acoustic threat from small vessel traffic like that facing the killer whales in Erbe's study. Nonetheless, there are potentially important conclusions related to, and drawn directly from their straits to consider for future Sanctuary management. First, CINMS is likely to sustain an increase in whale watching and small vessel traffic proportional to Southern California population growth and tourism, which could bring us closer to the situation facing the orca north of the Olympic Peninsula. Research, consideration and planning initiated now could preempt similar negative impacts on CINMS whales and dolphins resultant from poorly managed growth in "eco-tourism." Second, while no definitive connection has yet been drawn between excessive whale watching and the decline of the resident orca population (as Erbe (2002) herself points out), the circumstantial evidence indicating such a linkage is strong; preservation of the remaining resident orcas appears to necessitate a precautionary approach to conservation management, rather than an approach that waits on absolutely definitive science.

Finally, Erbe (2002) notes: "a major problem is posed by private whale-watchers, who can vastly outnumber commercial operators. Private people are unaware of the whale-watching code of ethics and often do not know how to watch whales properly." Off Santa Barbara and in the Sanctuary, motorboaters do often illegally pursue migrating gray whales and other marine mammals to close range, and also unintentionally harass the same animals by navigating quickly through important migration paths. As discussed above, such contact is known to cause significant stress-inducing avoidance response in marine mammals, and thus represents a distinct noise related impact on Sanctuary resources (Howorth 2004).

While the relatively dispersed character of motorized small vessel traffic in CINMS suggests that cumulative small vessel traffic is not currently a significant threat to the area, private power boaters that fail to adhere to the Marine Mammal Protection Act may negatively impact CINMS cetaceans due to both acoustic output and harassment associated with close following. Small vessel traffic will likely become more ecologically problematic for CINMS should total vessel numbers increase. The greater cumulative contribution to the Sanctuary's ambient noise level and the higher rates of motorboat noise/wildlife interaction would further heighten the need to address this acoustic threat to CINMS resource conservation. In the meantime, more Sanctuary-specific research is needed in this area, both to better determine small vessel traffic rates in the Sanctuary, and to gather quantitative data on the concomitant impacts to CINMS marine mammals. This could be particularly important in order to identify whether any CINMS animal communities suffer, or are near experiencing chronic exposure to small vessel traffic noise, which existing science suggests as potentially much more deleterious.

OIL AND GAS DEVELOPMENT

Offshore drilling and oil production in the Santa Barbara Channel may contribute to the acoustic environment of CINMS, however, current research suggests that direct acoustic contributions and impacts are low.[21] The limited completed research on noise from one drilling platform and three combination drilling/production platforms in the Santa Barbara Channel found that noise was "nearly undetectable even alongside the platform[s] during sea states [equal to or greater than] 3 [small waves, moderate breeze of 12-16 knots, wave heights 1.4 – 3ft]," with the strongest sound from all four platforms at an extremely low 5 Hz (Gales (1982), in Richardson et al. (1995)).

While noise output from platforms may be moderate overall, having peak amplitude at such low frequencies implies minimal attenuation of the emissions: Richardson et al. (1995) predict that noise from a production platform is audible to mysticetes to about 2.5 kilometers. Platform noise has also been shown to have a discernable if modest behavioral impact: migrating gray whales were observed to swim away from playbacks of drilling noise at levels corresponding to distances of less than 100 meters from an operating platform (Malme et al. 1984).

The fixed position of the noise source (the operating drill, gearing, generators and pumps) implies the possibility of avoidance as well as habituation for marine species; within some ranges masking of acoustic environmental information or communication from predators, prey or conspecifics may occur. In the Santa Barbara Channel however, rig noise has minimal impact on an array of marine mammal species based on anecdotal

21 / For a discussion regarding seismic exploratory activities, see pp. 26-29 above.

evidence. According to MMS biologist Mark Pierson, "migrating gray whales, humpback whales, and dolphins are all frequently seen near platforms, and... California sea lions use the lower decks and mooring buoys at all the OCS platforms as haul-out areas" (Pierson 2004).

Drilling and oil production also add noise to the surrounding marine environment from the helicopters and vessel traffic required to support platform operations. Acoustic implications from aircraft and small craft are addressed elsewhere in this document.

ACOUSTIC THERMOMETRY

Acoustic thermometry exploits how the velocity of sound varies in seawater of different temperatures and pressures in order to measure average temperature of an entire ocean. The "Acoustic Thermometry of the Ocean Climate" (ATOC) experiment was the first such project, which in December of 1995 began five years of intermittently broadcasting high-intensity, low-frequency sound from two sources, one off Kauai, and the second on the Pioneer Seamount approximately 80 kilometers offshore Half Moon Bay. ATOC receivers were positioned off Hawaii, New Zealand, the Aleutian Islands, and other locations about the Pacific, up to more than 6000 kilometers away from the sound source (ATOC 2003). In order to maintain a coherent signal over such ranges, the ATOC sound source transmitted at source levels of 195 dB centered at 75 Hz with a 37.5-Hz bandwidth (Costa et al. 2003) (a signal very similar to the Navy's low-frequency active sonar signal, due to being similarly optimized for transoceanic coherence and detectability).

During ATOC, biologists conducted monitoring and research to assess the impact of ATOC sound on whales and elephant seals, and reported minimal impacts:

> *In summary, all preliminary... results for the species so far selected for study reveal that a) animals do not vacate the Pioneer Seamount area during periods when the ATOC source is operating, b) northern elephant seals do not show any acute responses when exposed to the ATOC source, c) two species of odontocetes have poor hearing abilities in the 75 Hz range (a finding that is not unexpected and is in agreement with previous behavioral and anatomical evidence), d) humpback whales on the winter calving/breeding area off Big Island, Hawaii show no response when exposed to ATOC-like sounds at levels as high as 130 dB, and e) sperm whales on the summer feeding area off the Azores show no response when exposed to ATOC-like sounds at levels as high as 130 dB. Both these experimental playback received levels are as high or higher than the levels*

expected for animals directly above the operational ATOC source. [ATOC 2003][22]

However, ATOC's marine mammal researchers also reported that both humpback and sperm whales were more likely to be observed further from broadcasting sound sources than when the speakers weren't operating (WDCS 2003, citing Calambokidis 1998). Logically, the relative biological importance of the avoided ATOC ensonified habitat dictates the magnitude of impact to each species, but the documentation of impact implies that the addition of thermometry noise to a given ecology could be detrimental to it. Furthermore, specific research has yet to be conducted on impacts from acoustic thermometry on marine fishes, invertebrates or reptiles.

Continued Pacific acoustic thermometry is currently conducted as the "Northern Pacific Acoustic Laboratory experiment" (NPAL), however only the Kauai sound source, 80 miles north of the island, at a depth of 807 meters, is now operated. NPAL is permitted from 2002 until 2007 (WDCS 2003).

Acoustic thermometry is a capital-intensive endeavor that, almost ten years after the first application of the technology, remains isolated in application. The high-intensity sound levels involved in ATOC focused significant popular and scientific attention on anthropogenic underwater noise pollution; however acoustic thermometry does not appear to present a threat to CINMS in the foreseeable future. Hypothetical future projects proposing to broadcast sound in proximity to the Sanctuary may raise a similar suite of potential impacts as the Navy's application of LFAS due to the similarity in sound characteristics. However, while the towed arrays of LFAS tend to signal from the top of the ocean water column, acoustic thermometry sound sources broadcast from depths of hundreds of meters, suggesting that different biological communities (surface versus benthic) may be more or less intensely impacted.

22/ Excerpt from ATOC Marine Mammal Research Program "Quick Look," a summary of independent findings published as monthly reports from researchers including W. Au, J. Calambokidis, C. Croll, D. Costa and others. Available directly at: http://atoc.ucsd.edu/quicklookpg.html